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INVESTIGATION OF THE SCALE EFFECT OF CAVITATION EROSION

by

J. Varga, Gy. Sebestyen,et al.

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By: J. Varga, Gy. Sebestyen, et al.

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ABSTRACT: The paper presents results achieved up to date and surveys the methodologic problems which are the bases of research on the scale effect of cavitation erosion within the common research program of the Mechanical Institute of the Soviet Academy of Sciences and the Fluid Mechanical Working Group of the Hungarian Academy of Sciences at the Department of Hydraulic Machines, Budapest Technical University. The theoretical bases of the laboratory research methods for investigating the scale effect, based on an energetic parameter, are critically dealt with. The authors describe the experimental gear and the conditions with the aid of which the energetic parameter and the similarity criterion of the erosion are determined. The possible errors of the measured values and the influence of the errors on the final experimental results are analyzed. It is shown that the results of the experiments carried out at the Budapest Technical University confirm the earlier experiments, and thus the validity of the relation describing the scale effect is proved for a still larger range. English Translation: 27 pages.

INVESTIGATION OF THE SCALE EFFECT OF CAVITATION EROSION*

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I. INTRODUCTION

A situation in which operation in a state of cavitation is necessary for various periods of time, or in which local cavitation takes place in the machine, often arises in the use of hydraulic machines or devices. If insufficient consideration is given to this factor in the selection of the materials used in the manufacture of the equipment, severe damages may be caused and these damages may also lead to the destruction of the entire machine. Recognizing this factor, numerous theoretical and experimental research projects were conducted to elucidate the phenomena of cavitation erosion so as to learn about the processes that determine the intensity of the destruction. Much less attention has been given, however, to the clarification of the scale effect in cavitation erosion. Yet, the results of research can be utilized only to a limited extent in the construction of machines if this effect is not known.

The following discussion will summarize the experience gained in experiments designed to observe the erosion effect of cavitation zones behind circular cylinders. The experiments were conducted under consideration of the hydromechanical model law, and were aimed to clarify the scale effect of cavitation erosion on the basis of tests in which models of various geometrical dimensions were employed.

II. THE RESEARCH METHOD

1. The Intensity of Erosion

Various methods are employed for the investigation of the resistance of materials of construction to cavitation erosion [1].

Experiments conducted *in flowing liquid:* in these experiments, the sample fabricated from the material under test is subjected to cavitation; the cavitation forms behind the body immersed in the liquid.

Vibration and sonic methods. These methods involve magnetostrictive vibrations applied to the test samples, or test samples exposed to sonic and ultrasonic waves.

Rotating-disk method. The test sample is fabricated from the material to be tested, and is then mounted on the surface of a disk that rotates within the liquid. A protruding part is fitted to the surface of the disk or an indentation is produced on it; cavitation develops behind these, and the test sample is exposed to its effects.

Fluid-stream impact method. Test samples are mounted on a rotating disk: they are exposed periodically to the impact of a free stream of rapidly flowing fluid. It is to be assumed that the destruction process caused in this manner is the same as that caused by cavitation [2]. Since the validity of this assumption cannot be considered as having gained universal acceptance, it appeared desirable to favor tests in which the fluid stream exerts a direct effect.

In selecting the methods of test it appears that the aim should logically be to use methods most closely resembling the practical conditions, i.e., methods in which the cavitation effect caused by turbulence in the zone of detachment can be examined [3]. The method that most closely resembles the natural conditions and satisfies this requirement involves the study of the cavitation taking place behind bodies surrounded by a fluid flow. The attack of cavitation erosion on the materials requires a certain amount of energy; thus, it is desirable to create such conditions in tests performed in a fluid flow in which the relations are the least complicated between the intensity of the erosion and the resistance of the body immersed in the fluid, i.e., energy required to overcome the body resistance. For this reason, a circular-cylindrical model was selected as a first approximation: this model was inserted into the measuring channel of the hydrodynamic channel (Figs. 1 and 2). This selection is favorable for an additional reason: the flow may be considered as two-dimensional and the flow around a circular cylinder has been investigated so far in more detail than has been any other model [4-6].

There are parameters that indicate the intensity of the erosion and are not related with the hydrodynamic parameters of the flow [7]. This is so since the intensity of erosion can be measured on the basis of the following characteristic values:

a) depth and spread of the erosion voids [8, 9];

b) loss in sample weight after a specific period of time [10, 11];

c) volume loss related to unit area and time [1];

d) same as above, expressed as weight [12];

e) number of erosion voids formed on unit area within unit time [13];

f) volume loss of the sample, related to characteristic body dimensions [14];

g) decrease in the radiation intensity of isotopes that were placed on the surface of the test samples subjected to attack [15];

h) the time required to attain a given degree of destruction that can be followed visually [16].

Most of the parameters listed can be determined by measurements on the sample both prior to and following the experiments. The prevail-

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Fig. 1. Photograph of a cavitation zone created behind a circular cylinder: the picture was taken in the cavitation channel at the Chair for Hydraulic Machines, Budapest Technical University. $x = 0.85$; Re $=$ $= 6.6 \times 10^5$; $A = 198 \times 200$ sq mm; $d = .48$ mm; exposure time $t = 5 \times$ $\times 10^{-5}$ sec.

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Fig. 2. Picture of a cavitation zone created behind a circular cylinder, taken in the cavitation channel at the Chair for Hydraulic Machines, Budapest Technical University. $x = 1.23$; Re $= 6.35 \times 10^5$; $A = 198 \times$ $\times 200$ sq mm; $d = 48$ mm; exposure time $t = 2 \times 10^{-6}$ sec.

ing conditions and feasibility considerations affect generally the selection of the parameters. Thus, for example, the methods involving isotopes were selected for cavitation studies on Francis turbines. In addition to the above-named author, Rata [17] measured the change in the chemical resistance of the samples caused by erosion, and related this change to loss in volume. Govinda Rao [18] recommended dimensionless parameters for the characterization of cavitation erosion. Such a parameter is essentially a ratio characterizing the relation between the energy required for the destruction of a given volume of material and the energy of the collapsing bubbles. The energy of collapsing bubbles can be calculated on the basis of the Rayleigh theory [19] only if certain assumptions are valid – for example, the bubbles must be surrounded by a homogeneous fluid; furthermore, isothermal compression must be assumed – and therefore its value is uncertain. In the experiments of Govinda Rao, serving as the basis for the determination of the parameter, the cavitation zone consisted of a multitude of bubbles; thus, a homogeneous fluid surrounding was not ensured. The Govinda Rao parameter for cavitation erosion has a specific character; i.e., it depends on the degree of cavitation development and on the duration of the cavitation effect.

2. The Energetic Parameter

The energetic erosion parameter [7] designates the ratio of the eroded volume and a given portion of the cavitation resistance of the model. The unit of the energetic parameter consists of the reciprocal of the tensile energy of the material of unit volume. Contrary to all parameters listed above, the value of this parameter does not depend on a given state of cavitation; in the case of a given material, it depends neither on the flow rate nor on model dimensions or Reynoldsian and Weberian similarity criteria. The reciprocal of the energetic parameter represents the true cavitation resistance of the material subjected to cavitation erosion, in contrast to the other parameters that provide essentially the relative erosion resistance of the material: in other words, it is only possible to compare the resistance of a material with that of another.

In accordance with experiments involving the tensile work related to unit volume of metals – experiments of this nature were conducted by Gillemot and Sinay [20] – where the tensile work is independent of the nature of the mechanical forces causing the break and where it is also practically independent of the number of consecutive stresses involved in the tensile work; furthermore, it has a constant value for each material – the energetic parameter enables the designation of a mutual relation between the tensile work originating from cavitation work effects and the tensile work given by mechanical force effects. In the case of metals, that show no tendency to chemical corrosion even in the cavitation state, it is likely that the tensile work originating from cavitation stresses is the same as the tensile work originating from mechanical forces. To the extent that the destruction of metals in the course of cavitation is caused by corrosion effects, it is necessary to increase correspondingly the tensile work determined with the aid of the energetic parameter: this procedure yields the new parameter for the physical-mechanical properties of metals, viz., the cavitation resistance.

Within the context of Shalnev's definition [7], the energetic parameters may be expressed by the following equations:

$$\Delta V_e = \frac{\Delta V\, 10^7}{36\, \Delta C_x\, h d q_m v_m \gamma} \, [\mu^3 kp^{-1} m^{-1}];$$
$$\Delta V = \frac{\Delta G}{\gamma_s \tau} \, [mm^3 h^{-1}]; \quad q_m = \frac{v_m^2}{2g} \, [m];$$
$$\Delta C_x = C_{xt} - C_x + |\Delta C_x'| . \tag{1}$$

In these equations, ΔV represents the volume of the amount of eroded matter; ΔG represents the weight loss of the sample subjected to cavitation within the period τ; γ_s represents the specific gravity of the sample material; d represents the diameter of the cylinder; h represents the height of the cylinder; v_∞ represents the flow rate in the cross section restricted by the cylinder; γ represents the specific gravity of the fluid; C_x represents the resistance of the cylinder without cavitation; C_{xo} represents the resistance of the cylinder in case of cavitation; $\Delta C_x'$ represents that portion of the cavitation resistance which is obtained with the aid of the expression $C_{xo}-C_x = f(W)$, i.e., extrapolation of the *Weber* number to the value $W = 0$. The *Weber* number is defined as $W = \rho v^2_\infty d/\sigma$, where ρ represents the density of the fluid and σ represents the surface tension.

3. The Scale Effect

The energetic parameter makes the determination of the scale effect possible, i.e., it is possible to establish the volume loss of the material used in the full-scale part from data gathered in a model experiment. Provided that the cavitation conditions are geometrically similar and the fluids are the same, the following expression is obtained on the basis of a comparison of the expressions relating to the model and the full-scale part (1) respectively:

$$\Delta V_n = \Delta V_m L^\alpha V^\beta, \qquad (2)$$

In this expression, L represents a reference value related to the linear dimensions of the model and to the cavitation, and V is a scale value related to the flow rate.

Equation (2) provides the conditions that need to be considered in the execution of model experiments on cavitation erosion. In experiments conducted on the basis of Eq. (1) the exponent values of $\alpha = 3$ and $\beta = 5$ were obtained.

These values were confirmed by experiments conducted by other authors also. Knapp [13] conducted experiments on axially symmetrical models and full-size turbines [21]: he estimated the intensity of cavitation erosion on the basis of the number of cavities, and obtained the value of β 4-6. Kerr and Rosenberg, on the basis of their tests involving the use of isotopes in the scale of 1:1 [15] assume that the value is likely to be $\beta = 5$. Rata obtained in his experiments [17], conducted at various relatively close velocities, exponent values between $\beta = 4$ and $\beta = 8$. Govinda Rao [18] found in his tests involving cylinders, the values of $\beta = 5.3$ to $\beta = 8$, and in tests involving square prisms the values of $\beta = 4$ to $\beta = 8$.

The effect of model dimensions established on the basis of our experiments are shown in Table 1. This table gives the following values: volume of the amount of eroded substance in four cylinders of different dimensions, and the ten ratios at four different velocities derived from these values. The experimental value of α can be determined from these data. The average values of the volume ratios give a value of $\alpha = 2.95$; this is close to the theoretical value of $\alpha = 3$.

No other researchers have so far conducted experiments in this manner for the study of the effects of dimensions. Knapp [13] disputes the effects of dimensions on the intensity of erosion. The scattering of the results shows primarily how carefully one must proceed with respect to all values in the test setup that affect erosion intensity.

III. TEST SETUPS

1. The Water Channels

The cavitation erosion tests were conducted in the water channels designated as GT-3 and GT-2 at the Institute for Mechanics (IM), Soviet Academy of Sciences, and in the water channels of the Hungarian Academy of Sciences, located at the Department of Hydraulic Machines, Budapest Technical University [22]. All these channels have a closed water cycle, circulation being affected with the aid of pumps. The flow rate is regulated with the aid of control of the electrical drive. Pressure may be regulated independently of flow rate. The maximum attainable

TABLE 1

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	0,10	1,74	—	73,4	9,7	3,28	—	—	—	—	600	2,89	62,3	2,70
27	0,36	4,30	60,2	—	4,0	2,58	63,5	2,90	10,7	3,42	—	—	—	—
30	1,78	15,42	101	—	8,5	3,09	57	2,92	6,6	2,72	—	—	—	—
28	2,96	10,2	—	—	7,4	2,09	—	—	—	—	—	—	—	—
					a_{mean} [1]	2,96		2,96		3,07		2,89		2,70

[1] $\sum a_{mean} = 2,95$

1) Average.

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flow rate within the measuring length of 200 × 48 sq mm is 18m/s for the channel of Budapest Technical University. In the channels of IM the flow rate can be varied between 0 and 25 m/s for the channels with varying dimensions. The cross section of the measuring channel at Budapest Technical University is illustrated in Fig. 3.

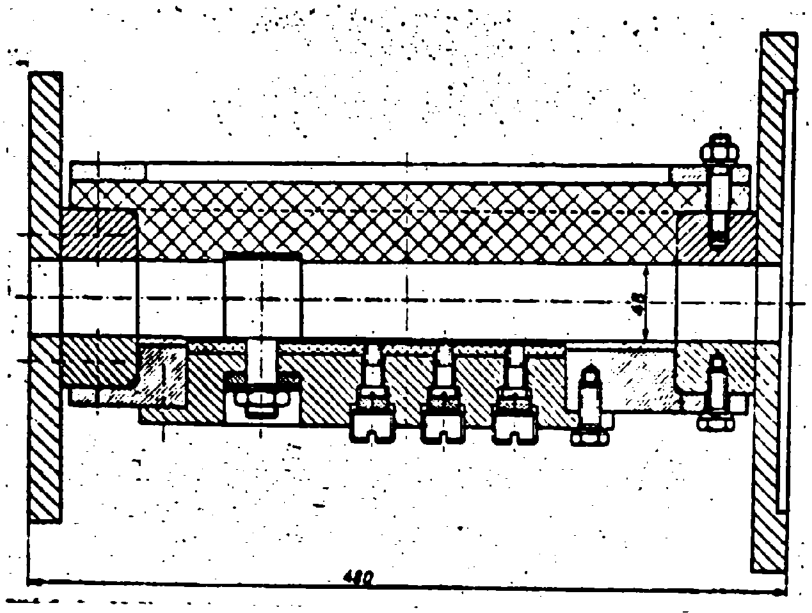

Fig. 3. The measuring channel at the Department of Hydraulic Machines at Budapest Technical University, with sample in the channel. The cross-sectional dimensions of the measuring length are: $A = 48 \times 200$ sq mm; diameter of the circular cylinder: $d = 48$ mm.

2. The Converging Section of the Diffuser

The converging section of the diffuser is fitted between the pressure tank and the measuring stretch. The converging section of the diffuser fitted into the channel must be considered as being subject to very stringent requirements since it determines the nature of the flow in the measuring channel. Thus, the converging section of the diffuser must be constructed so that it ensures the highest possible degree of uniformity in the entire cross section of the measuring channel, i.e., that there are minimal changes only in flow rate both longitudinally configuration. The constriction ratio between the inflow and outflow cross sections for the converging section of the diffuser was established on the basis of the relevant studies of Prandtl [23]. The longitudinal profile of the converging section of the diffuser consists of two curves. The curve at the inflow side ensures a suitable connection for the outflow side of the converging section of the diffuser, the profile of which has been calculated according to the data reported by Witoszynski [24] (Fig. 4).

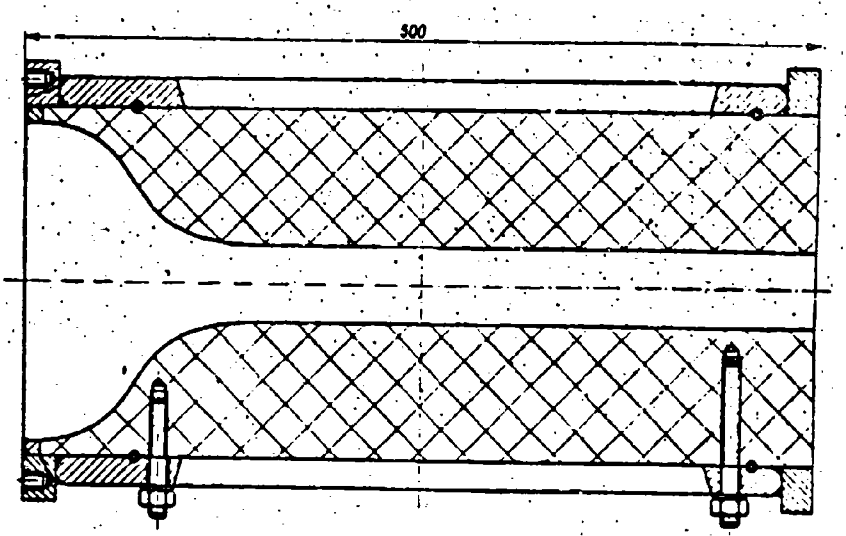

Fig. 4. The converging section of the diffuser of the measuring channel in the cavitation channel at the Department of Hydraulic Machines, Budapest Technical University. Dimensions of the outflow cross section: $A = 48 \times 200$ sq mm.

To prevent the formation of a turbulent zone, the length of the second part of the converging section of the diffuser that located in the measuring stretch, was executed with the values according to expression $l = 3d$. The converging section of the diffuser is employed – after calibration – for measuring the amount of fluid flowing through the measuring stretch and of the flow rate.

3. The Measuring Channel

Cavitation erosion tests were conducted with four different cross sections in the three water channels described above. The cross sectional dimensions of the measuring stretches are as follows:

a) in the channels of the Institute for Mechanics: 6 × 25; 12 × × 50; 24 × 100 sq mm;

b) in the channel of Budapest Technical University: 48 × 200 sq mm.

The subsequent executions provide data on the measuring channel with the cross section of 48 × 200 sq mm in the cavitation channel at the Department of Hydraulic Machines, Budapest Technical University. The chassis of the measuring channel is formed by two steel frames of identical size: these frames are kept 48 mm apart by four spacers fitted in the corners. The profile cross section, bounded by the spacers and frame edges, is 48 × 200 sq mm. The two ends of the measuring channel are connected to a part that also contains the converging and diverging section of the diffuser, respectively, by means of flange connections. Openings are provided in the steel frames for the fitting of appropriate end pieces. To permit visual observation and photographic recording, three sides are covered with Plexiglas and one side is covered with an end plate having a wider opening. The latter opening serves for the introduction of the sample fabricated for the test and of the sample holder through the end plate. The insertion and removal of the sample can thus be accomplished in a simple manner.

The sample employed for the tests consists of two parts, viz., the so-called carrier disk and the rolled lead sheet subjected to erosion. The lead sheet was affixed to the aluminum-alloy baseplate by means of metal cement. There are drilled holes in this baseplate to permit attachment of the sample holders.

gree of precision, and the surfaces were carefully worked. As can be seen from the figure, one end of the circular cylinder is mounted in the sample holder while the other end extends into a drilled hole provided for this purpose in the opposite Plexiglas window.

4. The Design of the Diffuser

The diffuser was designed with great care, considering the fact that the diffuser is the most sensitive component of the water channel insofar as cavitation is concerned, and it also determines the quality level of the channel. On the basis of these considerations, a 7° opening angle was selected for the diffuser, i.e., an angle smaller than that advocated for wind tunnels. In order to be able to fabricate the diffuser with ease, it consists of several parts, with due consideration of the fact that there must be a transition from a four-edge profile to a circular profile.

IV. DETERMINATION OF THE BASIC VALUES

1. Determination of the Velocities in the Measuring Cross Section

The average flow rate of the stream is generally determined for the model cross section on the basis of the amount of water flown through: this can be determined in various ways (a measuring fitting, a Venturi gauge, etc.). The flow rate can be determined also with the aid of the pressure obtained through a hole drilled into the cylinder along the flow axis. In the water channel, determination of the flow rate can be effected on the basis of the following considerations: let

p_1 denote the pressure at the converging section of the diffuser entry,

p_2 denote the pressure measured at the outflow of the converging section of the diffuser,

p_3 denote the pressure at the entry of the measuring stretch, and

p_4 denote the pressure measured at the wall of the measuring stretch at a point corresponding to the centerline of the cylinder if the cylinder is not inserted in the measuring channel.

If p_a denote the pressure at the forward point of the centerline of the cylinder inserted in the flow, it is necessary to establish experimentally the relations

$$p_a - p_4 = f(p_1 - p_2)$$

or

$$p_3 - p_4 = f(p_1 - p_2)$$

$$(p_a - p_4) - (p_3 - p_4) = q = f(p_1 - p_2)$$

where $q = v_0^2/2g$, and then determine graphically [25] the values

$$v_0 = f(p_1 - p_2), \quad v_0 = \sqrt{2gq}$$

Considering the cross section constriction caused by the cylinder, we obtain the following expression:

$$v_\infty = v\frac{b}{b-d},$$

where b represents the width of the measuring stretch. The following velocities are employed in the evaluation of the test results: v, the average velocity before the model; v_∞, the average velocity obtained under consideration of the cross section constriction of the flow; $v_{\infty 0}$, the velocity at the centerline of the flow, considering the channel constriction. Precise determination of the velocity values is a very important task since the volume of the eroded substance depends on the exponent $\beta = 5$.

2. <u>Determination of the Pressure in the Measuring Cross Section</u>

It is not possible to determine the pressure p_1 directly in the measuring cross section. In the course of the tests, measurement is accomplished by measuring the pressure p_3 before the model. By utilizing the expression

$$p_3 - p_1 = f(p_3 - p_2)$$

without a cylinder being inserted, the above-mentioned pressure is obtained from the equation $p_4 = p_3-(p_3-p_4)$ which includes consideration of the pressure drop between points 3 and 4 in the measuring stretch.

3. Determination of the Cavitation Number (κ)

Determination of the cavitation number is necessary for the calculation of the value of ΔC_x. This value may be determined with or without consideration of the constriction. In the former case the following expression applies:

$$\kappa = \frac{p_\infty - p_d}{\gamma q_n},$$

where $p_\infty = p_4, q_n$ represents the level of velocity found according to the above-mentioned method (cf. IV.1). p_d represents the pressure of water vapor at the given temperature, and γ represents the specific gravity of water.

4. Length of the Cavitation Zone

The length of the cavitation zone is measured with the aid of the distance between the centerline of the cylinder and the end of the connected part: it is denoted as l_c. Expressed in a dimensionless form, $\lambda = l_c/d$ characterizes the so-called relative zone length, where d represents the diameter of the cylinder.

5. Determination of ΔC_x

The expressions $C_x(Re, \kappa)$ and $\lambda(\kappa)$ are employed for the determination of ΔC_x. More about this may be found in References [4] and [7] (Figs. 5 and 6). It is desirable to extend the data given there from both the range of large and the range of small *Reynolds* numbers in order to obtain as reliable values as possible for the value of C_x. The simplest, and at the same time also the most accurate, method for the determination of the value of C_x involves the determination of the pressure distribution in the center cross section of the model. In determinations made by using another method, such as, for example, in case of direct force measurement, the cracks necessarily present in the assembly cause a distortion of the flow.

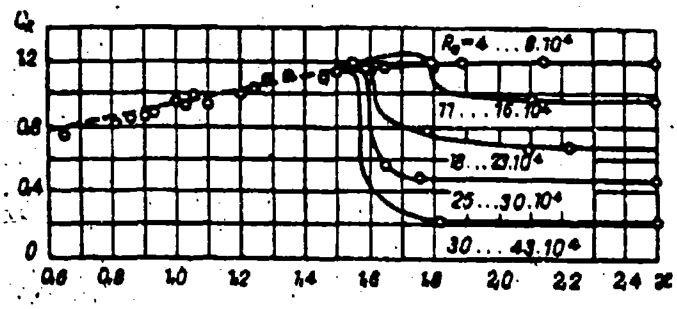

Fig. 5. Effect of the Reynolds number and the cavitation number on the cylinder resistance number.

$Re = 4 \div 8 \cdot 10^4$, $d = 5,10$ mm; $Re = 11 \div 16 \cdot 10^4$, $d = 20$ mm; $Re = 18 \div 23 \cdot 10^4$, $d = 30$ mm; $Re = 25 \div 30 \cdot 10^4$, $d = 40$ mm; $Re = 30 \div 43 \cdot 10^4$, $d = 50$ mm.

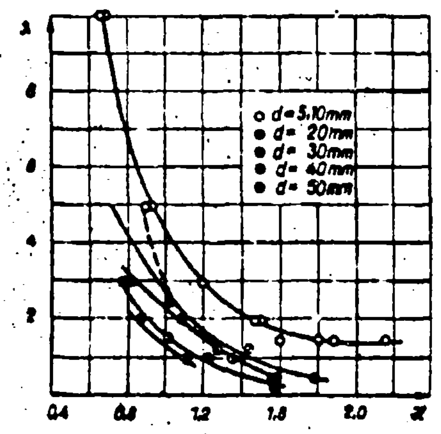

Fig. 6. Effect of the cavitation number and the cylinder diameter on the length of the cavitation zone.

The functions $C_x = C_x(W)$ and $C_{xo} = C_{xo}(W)$ (Fig. 7) can be represented on the basis of the expressions $C_x(Re, \kappa)$ and $\lambda(\kappa)$. Within the meaning of Eq. (1), in order to determine the value of ΔC_x it is also the absolute value of a magnitude obtained by forming the differences $C_{xo}(W)-C_x(W)$ as a function of W, and interpolating them to yield a line that, in turn, intersects the above value in the negative area of ordinate C_x by extrapolation to $W = 0$.

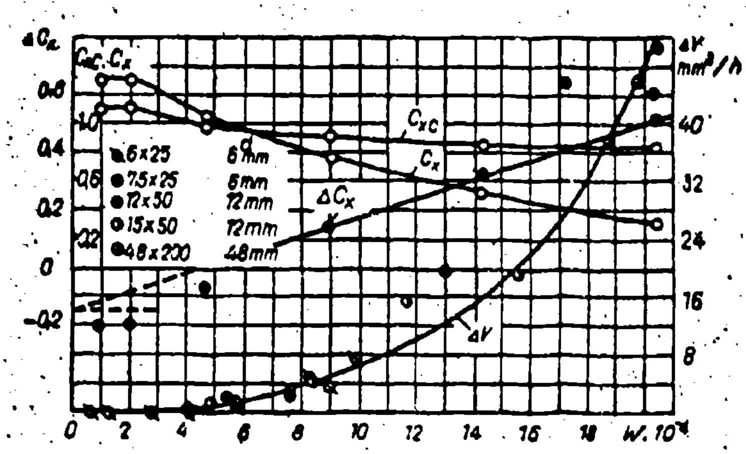

Fig. 7. The values C_x, C_{xo}, ΔC_x, and ΔV in relation to the Weber number (W).

6. Determination of ΔV

The volume of the eroded material can be determined from both the weight loss, ΔG, and the duration of the experiment, τ, i.e.,

$$\Delta V = \frac{\Delta G}{\gamma_s \tau} \, [\mathrm{mm}^3 \, \mathrm{h}^{-1}],$$

where λ_s represents the specific gravity of the sample material. In order to avoid errors, it is desitable to determine in advance the expression $\Delta V = f(W)$ on the basis of tests, thereby obtaining a suitable number of values for ΔV. The expression $\Delta V = f(W)$ can be constructed from the averages of the values of ΔV obtained (see Fig. 7).

7. Determination of ΔG

The weight loss of the sample in the experiment can be determined by weighing – at the required degree of accuracy – the sample both prior to and following the test. The accuracy of the weighing depends on the value of ΔG. The acceptable degree of accuracy for the weighing – in comparison to the determination accuracy of other values – is represented by a tolerance of $\pm 1\%$; however, we were able to execute the weighings in the tests, especially in the case of larger samples, at a considerably greater degree of accuracy ($\pm 0.1\%$).

8. Determination of τ

The duration of the test is determined by the purpose of the experiment and by factors contributing to the accuracy of the test results (cf. Chapter 5). In tests executed at constant values of d and λ, with the velocity being varied, the duration of the test is characterized by the time required for attaining the same loss in weight. When, however, the dimensions of the model are varied, the duration of the test is determined by the expression $\Delta G_n/\Delta G_m \cong L^3$.

9. The Water Temperature

The water temperature is measured by a mercury thermometer placed in an oil-filled boring of the converging section of the diffuser flange.

10. Additional Values

The barometric pressure is measured with a mercury manometer. The values required for the calculation of Expressions (1) and (2), such as the specific gravity of the water, γ, the specific gravity of the sample material, γ_s, the water vapor pressure, p_d, the surface tension, σ, the kinematic viscosity ν of the water, are taken from tables containing the required physical constants.

V. FACTORS AFFECTING THE ACCURACY OF THE RESULTS

1. Effect of the Air Content

Cavitation tests were performed with the aid of magnetostrictive water exerts a significant influence on the intensity of the erosion. The erosion loss is approximately 80% higher in distilled water than in tap water. The erosion losses determined in tap water become about 30% lower if the water is aerated. These experiences indicate that in tests designed to determine cavitation erosion it is necessary to use water that has a constant air content. Thus, the water channels used in these tests are designed so that the water surface in the pressure containers is in no direct contact with the air, and that the refilling of the channel is always accomplished with water that has constant properties.

2. Effect of Temperature

In the course of our tests [3], where we held the dimensions and the state of the cavitation zone, and also the flow rate, at constant values, we established that fluctuations of water temperature between 10° and 26°C reduced the erosion by 0-7% (Fig. 8). Where we restricted the fluctuations of water temperature to 1°-8°C, the effect of temperature increase was insignificant. In the course of our tests, we allowed temperature fluctuations of ± 5°C.

3. Effect of Cavitation State

Our investigations [3] show the maximum intensity of erosion in case of cavitation behind a circular cylinder, at a value of $\lambda = 3$ for the cavitation zone length (Fig. 9). The erosion intensity decreased by approximately 25% by changing the value of $\lambda = 3$ to $\lambda = 2$, and by at least 16% by changing the value to up to $\lambda = 4$. Considering this state of affairs, a maximum error of $\delta_G = \pm 5\%$ may arise in the determination of ΔG.

4. Effect of the Dimension Ratios of the Model

In our tests the effect of the size ratio of l/d is essentially

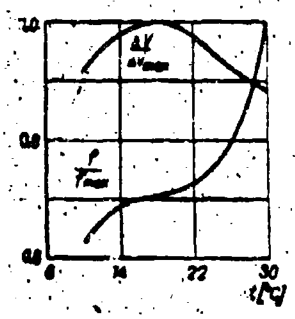

Fig. 8. The compensated functions of the relative erosion volume [$\Delta V/\Delta V_{max}$] or the relative erosion surface [f/fmax] and the water temperature (t, °C).

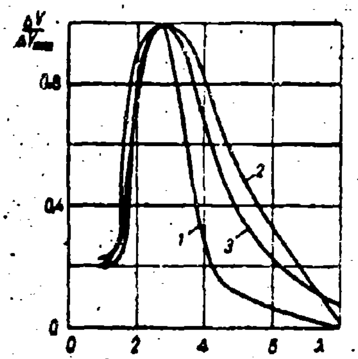

Fig. 9. The compensated functions of the relative erosion volume [$\Delta V/\Delta V_{max}$] and the relative length of the cavitation zone (λ). 1) At a velocity of $v_0 = 14$ m/s; 2) at a velocity of $v_0 = 17$ m/s; 3) at a velocity of $v_0 = 20$ m/s.

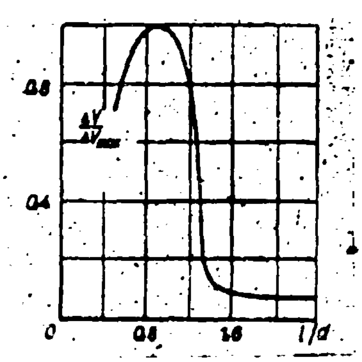

Fig. 10. Compensated functions of relative volume of erosion [$\Delta V/\Delta V_{max}$] and relative dimensions of the model [l/d].

the same as the effect of the width of the measuring channel cross section. Our research report [1] indicates that the intensity of the erosion attains its maximum value at a dimension ratio of $l/d = 1$ (Fig. 10). The intensity of the erosion decreases suddenly with an increasing l/d ratio. By increasing the l/d ratio by 10%, the intensity of the erosion also decreases by 10%, however, by increasing the l/d ratio by 30%, the intensity decreases to one-third to one-fourth of its initial value. We were able to maintain the l/d ratio within 1% in our tests; thus, the maximum error in the determination of ΔV was less than 1%.

By determining the expression $\Delta G(\tau)$ for various metals, it can be established that there is a so-called incubation period in elastic metals, and that during this period there is merely a deformation of the surface layer without any loss in weight (strain-hardening). A weight-loss curve of this type is shown in Fig. 11. For the lead sample employed, the value of ΔG increases in an approximately linear manner as a function time up to a certain limit. Within this period, pronounced eroded surfaces form on the surface of the material, generally in the form of circular indentations. Since it can be assumed that further local cavitation will become evident in the vicinity of the indentations, that were caused by cavitation attack, it appears desirable, for the sake of comparability of the test results, to select that period from the entire test duration during which only the cavitation erosion, caused by the original flow pattern, manifests itself.

6. Effect of the Surface Quality of the Sample

The effect of the surface quality of the sample was clarified by earlier tests [7]: in these tests, comparative studies were conducted with samples having different types of surface roughness. According to the experiences gained in these studies, all tests must be conducted with samples having the same degree of surface roughness if it is desired to obtain comparable values.

7. Effect of the Test Range

As mentioned earlier, the exponent value of the scale factor was established by various researchers to be in the $\beta = 4$-8 range. By employing the data obtained by Govinda Rao in extensive tests [27], it is possible to conclude that an exponent value of $\beta = 5$ is obtained both in the case of cylinder inserted in the flow and in the case of tests performed in a Venturi tube, provided that the very low velocity range is excluded. Some tests were conducted at three velocities – obviously too small a number – by considering the fact that expression $\Delta V(v)$ was determined graphically. The very wide range of $\beta = 4-8$ obtained from the test of *Rata* for the value of the exponent may be explained also in terms of incidental errors, since in these tests the velocities were close to the value of $v = 30-40$ m/sec.

8. The Highest Possible Error in the Determination of ΔV_0 and ΔV_n

By employing an approximating calculation method [28], the following expression is obtained for the characterization of the maximum possible error in the determination of the value of ΔV_0:

$$\delta_0 = \delta_G + \delta_t + \delta_{Cx} + \delta_\lambda + \delta_d + 3\delta_v + \delta_\xi + \delta_\gamma ;$$

for the value of ΔV_n:

$$\delta_n = \delta_m + 3\delta_L + 5\delta_V = \delta_m + 3 \cdot 2\delta_l + 5 \cdot 2\delta_{v_0} .$$

The subscripts represent the maximum possible errors for the values involved. In the determination of the value of δ_G, it is not permissible to start from the accuracy of the weighing of the sample alone, the basis to be employed must also include the deviation of the value of λ, l/d, and other above-mentioned factors, from constancy. On the basis of these considerations, the following expressions may be derived:

$$\delta_0 = 0{,}05 + 0{,}01 + 0{,}05 + 0{,}005 + 0{,}005 + 3 \cdot 0{,}02 + 0 + 0 = 0{,}18 \approx \pm 18\%$$

and

$$\delta_n = 0{,}06 + 3 \cdot 2 \cdot 0{,}005 + 5 \cdot 2 \cdot 0{,}02 = 0{,}29 \sim \pm 30\% .$$

These relatively high values for the possible error explain the scattering of the experimentally determined values for ΔV_0 [7], shown in the figure. The error in the determination of the erosion intensity may become especially large if the tests are conducted with the actual machines.

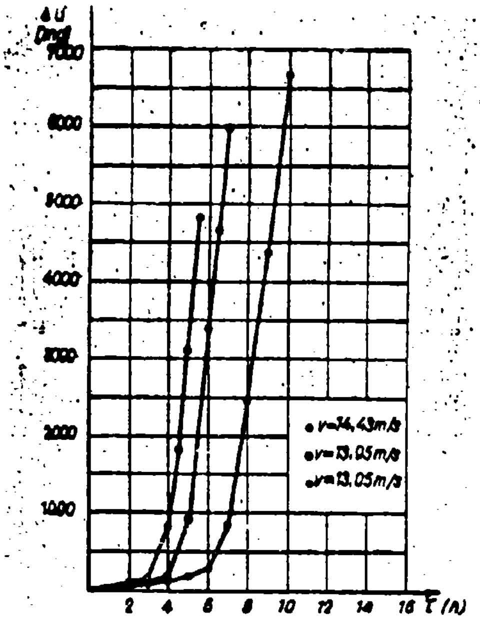

Fig. 11. The experimental functions of erosive weight loss ΔG and duration of the erosion study (τ).

VI. CONCLUSIONS

Especial attention has to be paid in the investigation of the scale effect of cavitation erosion to the following factors:

a) the accuracy of the determination of the cavitation resistance and of the flow rate; furthermore, the determination of the volume loss by the erosion;

b) maintenance of the identity of the cavitation state and the dimensional ratios of the test models employed;

c) proper setting of the test duration. In order to reduce the magnitude of the errors, the tests are to be conducted in a wide range of velocities and with a large number of variations.

The results obtained at Budapest Technical University confirmed the test results obtained earlier; furthermore, they confirm the validity of the relation employed for the scale effect for an additional range.

REFERENCES

1. Shal'nev, K.K., Gidromekhanicheskiye aspekty kavitatsionnoy erozii. [Hydromechanical Aspects of Cavitation Erosion]. Izv. AN SSSR Otd. tekhn. n. [Bull. USSR Acad. Sci. Dept. of Tech. Sci.] (1958), No. 1.
2. Vasvari, F., Beginnende Zerstörung von Metalloberflächen durch Wasserschlag [Impending Destruction of Metal Surfaces by Water Impingement]; Periodice Polytechnica [Journal of the Polytechnical University], Vol. 6, 1962, No. 1.
3. Shal'nev, K.K., Usloviya intensivnosti kavitatsionnoy erozii. [Conditions of Cavitation-Erosion Intensity]. Izv. AN SSR Otd. tekhn. n. [Bull. USSR Acad. Sci. Dept. of Tech. Sci.] (1956) No. 1.
4. Konstantinov, B.A., Vliyaniye chisla Reynol'dsa na otryvnoye obtekaniye. [Effect of Reynolds Number on Separation Streamlining]. Izv. AN SSSR, Otd. tekhn. n. (1946), No. 10.
5. Martyrer, E., Kraftmessungen an Wiederstandskörpern und Flügelprofilen in Wasserstrom bei Kavitation [Force Measurements on Resistance Bodies and Wing Profiles in a Stream of Water under Cavitation], (G. Kempf and E. Foerster: Hydromechanische Probleme des Schiffsantriebes [Hydromechanical Problems in Ship Propulsion]), Hamburg, 1932.
6. Silbermann, E., Experimental Studies of Supercavitating Flow about Simple Two-Dimensional Bodies in a Jet. Journal of Fluid Mechanics, 5 (1959), 337-354.

7. Shal'nev, K.K., Energeticheskiy parametr i masshtabnyy effekt kavitatsionnoy erozii. [Energy Parameter and Scale Effect of Cavitation Erosion]. Izv. AN SSR Otd. tekhn. n. [Bull. USSR Acad. Sci. Dept. of Tech. Sci.] (1961), No. 5.

8. Plesset, M.S., Ellis, A.T., On the Mechanism of Cavitation Damage. Trans. ASME 77 (1955), No. 7.

9. Parsons, C.A., Cook, S.S. Investigations into the Causes of Corrosion or Erosion of Propellers. Engineering 107 (1919).

10. Kerr, S.I. Determination of the Relative Resistance to Cavitation Erosion by the Vibratory Method. Trans. ASME 59 (1937), No. 5.

11. Mousson, J.M., Pitting Resistance of Metals under Cavitation. Trans. ASME 59 (1937), No. 5.

12. Gavranek, V.V., Izucheniye kavitatsionnoy erozii metallicheskikh materialov na magnitostriktsionnom vibratore.[Study of Cavitation Erosion in Metallic Materials on a Magnetostrictive Vibrator], KHPI im. V.I. Lenina [The Lenin Chemistry and Physics Institute], 9 (1957), No. 1.

13. Knapp, R.T., Recent Investigation of the Mechanics of Cavitation Damage. Trans. ASME 77 (1955), No. 7.

14. Noskievic, J., Beitrag zur Ähnlichkeit bei Kavitation [Contribution to Similarity in Cavitation], Bergakademie [Mining Academy], Vol. 8, 1956, No. 2.

15. Kerr, S.K., Rosenberg, K., An Index of Cavitation Erosion by Means of Radioisotope. Trans. ASME 80 (1958), No. 6.

16. Schröter, H., Korrosion durch Kavitation in einem Diffusor [Cavitation Erosion in a Diffuser], Z. VDI [Journal of the Association of German Engineers], Vol. 76, 1932, No. 21.

17. Rata, J.M., Erosion de cavitation. Mesure de l'érosion par

jauges résistantes [Cavitation Erosion. Measure of Erosion by Resistance Gauges]. Symposium Recherche sur les Turbines Hydrauliques de Nice [Nice Symposium on Hydraulic Turbine Research], 16-20 Sept. 1960.

18. Govinda Rao, N.S., Thiruvengadam, A., Prediction of Cavitation Damage. J. Hydraul. Div. Proc. Amer. Soc. Civil Engrs. 87 (1961), No. Hy. 5.

19. Rayleigh, On the Pressure Developed in a Liquid During the Collapse of a Spherical Cavity. Phil. Mag. Ser. 4, 34 (1917).

20. Gillemot, L., and Sinay, F., Die Brucharbeit als Werkstoffkenngrösse [Tensile Work as a Material Parameter], Acta Techn. Hung. [Proceedings of the Hungarian Academy of Sciences, Technology], Vol. 22, 1958, No. 1-2.

21. Knapp, R.T., Accelerated Field Tests of Cavitation Intensity. Trans. ASME 80 (1958), No. 1.

22. Fay, Cs., A Vizgépek Tanszékének kavitacios csatornaja [The Cavitation Channel at the Department of Hydraulic Machines], MTA Musz. Tud. Oszt. Közl. [Reports of the Section for Technical Sciences, Hungarian Academy of Sciences], Vol. 22, 1958, No. 1-3.

23. Prandtl, L., Herstellung einwandfreier Luftströme [Generation of Perfect Air Flows], Handbuch der Experimentalphysik [Handbook of Experimental Physics], 1932, Vol. 4, Part 2.

24. Witoszynski, E., Über Strahlerweiterung und Strahlablenkung [On Flow Expansion and Flow Deflection], Vorträge aus dem Gebiete der Hydro- und Aerodynamik [Lectures in the Fields of Hydrodynamics and Aerodynamics], Berlin, 1924.

25. Shal'nev, K.K., Kavitatsiya nerovnostey poverkhnosti treugol'nogo profilya [Cavitation in Irregularities on Triangular

Surface Profiles], PMTF [Journal of Applied Mechanics and Technical Physics] (1962), No. 6.

26. Novotny, H., Werkstoffzerstörung durch Kavitation [Destruction of Materials by Cavitation], VDI Verlag [Publishing House of the Association of German Engineers], Berlin, 1942.

27. Govinda Rao, N.S., Cavitation – its Inception and Damage. Irrigat. and Power 18 (1961), No. 1.

28. Frank, M.P., Elementarnye priblizhennye vychisleniya [Elementary Approximate Calculations], Moskva [Moscow], 1932.

29. Varga, I.I., Chernyavskiy, B.A., Shal'nev, K.K., O metode issledovaniya masshtabnogo effekta kavitatsionnoy erozii. [A Method for the Study of the Scale Effect in Cavitation Erosion]. Zh. Prikl. Mekh. i Tekhn. Fiz. AN SSR, Moskva [Journal of Applied Mechanics and Technical Physics of the USSR Academy of Sciences, Moscow] (1963), No. 3, 122-129.

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1	Part of the text of this report was published in the Russian language, under Reference [29] in the list of references.